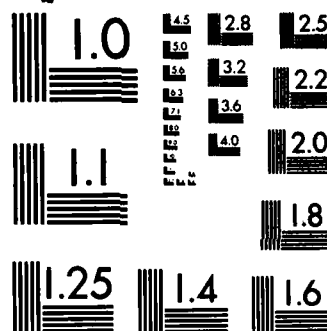AD-A163 091   CONFIRMATION OF A 152-DAY PERIODICITY IN THE OCCURRENCE   1/1
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CONFIRMATION OF A 152-DAY PERIODICITY IN THE OCCURRENCE OF SOLAR FLARES INFERRED FROM MICROWAVE DATA

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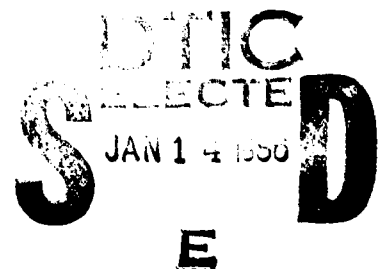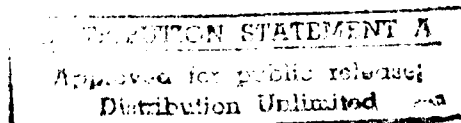
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Abstract

Evidence for a periodicity of about 155 ± 5 days in the production of energetic solar flares has been reported by Rieger *et al.* (1984) and Kiplinger *et al.* (1984). The data on which these analyses were based are restricted to the years 1980 through early 1984. To see whether this periodicity is a persistent phenomenon, we have examined the occurrences of flares inferred from microwave data, which are available for most of the present and previous solar cycles. We find strong confirmation of a 152-day periodicity in the time interval previously studied, demonstrating that these flares are a useful indicator for the observed periodicity. We find evidence for persistence of the periodicity in the previous cycle (Cycle 20). In Cycle 20 the periodic modulation of the flare occurrence rate was weaker than in Cycle 21, but the phase has apparently remained coherent through both cycles.

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Introduction

Rieger *et al.* (1984) have reported evidence for a 154-day periodicity in the occurrence of solar flares based on observations of the hard x- and gamma-ray continuum above 300 keV, made with the Gamma-Ray Spectrometer aboard the Solar Maximum Mission (SMM) satellite from February 1980 to June 1983. By analyzing the hard x-ray flares observed with the Hard X-Ray Burst Spectrometer on the same satellite, Kiplinger *et al.* (1984) also found evidence for periodicity at a similar period of 158 days. Rieger *et al.* pointed out weak confirmation for the 154-day periodicity in the modulation of solar activity as measured by the sunspot number, but could not confirm persistence of the effect in previous solar cycles. Furthermore, Kiplinger *et al.* claim that the effect they observed may have been transient. Since the cause of the periodicity is not known at all, and since such a periodicity is a potential forecasting tool, it is important to establish whether the periodicity can be observed in data over a longer time span. Because SMM was launched in February 1980, this cannot be done with flare data based on direct hard x- or gamma-ray observations. Soft x-ray data from the Geostationary Orbiting Environmental Satellites (GOES) are likewise limited to times since 1978.

The energetic electrons emitting hard x-rays during flares also typically emit microwaves at frequencies above 1 GHz via gyro-synchrotron radiation (Shevgaonkar and Kundu, 1985). Because the data base of microwave observations covers a comparatively long time span, we have investigated it as an alternative to the hard x-ray data. We have analyzed the occurrence rate of flares which we have inferred from the microwave observations reported in Solar Radio Noise Data as compiled by the World Data Center A in Boulder from reports by about 50 stations worldwide. (See Solar-Geophysical Data 1984 for a recent description of the data.) We have restricted our analysis to the period 1966 April 1 through 1983 December 31, during which reporting by at least some stations has been essentially continuous.

Flares are not identified and grouped together as such in the data, so we have employed an automatic procedure to identify flares of interest among the frequently overlapping individual station reports of flare and non-flare events at many frequencies. Our identification process accepts all reports at frequencies of at least 1 Ghz with an identified starting time and peak time, duration of at most 30 minutes, a Burst Type Code corresponding to one of the flare types (1-8, 20-23, 40-42, and 45-49), and peak flux greater than some specified cutoff; we have used cutoffs of 10, 30, and 100 solar flux units (10^{-22} Watt/m^2/Hz). If a duration is not given, we have

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used the interval from start to peak as the duration. All reports overlapping in time are then combined into a single "identified flare". The number of such flares based on events exceeding the 10 sfu threshold is 21,847, of which about 45% occur after Jan. 1, 1980. Five-day means of the daily count of these flares during the entire reporting interval are shown in Figure 1. Reports of radio noise events at frequencies below 1 GHz were not included because below this frequency radiation by various plasma processes generally dominates (Wild, Smerd, and Weiss 1963). The 30-minute cutoff in duration was imposed to prevent reports of very long duration from masking multiple flares. About 16% of otherwise eligible reports were excluded on this basis, but the total number of identified flares was increased by about 15%.

Analysis

We have computed power spectra for the time dependence of flares identified from the microwave data by binning into one-day flare counts (see Fig. 1), normalizing the daily counts to zero mean and unit variance, and computing an oversampled fast Fourier transform power spectrum. Separate power spectra for flares exceeding the 10 sfu threshold during Solar Cycles 20 and 21 are shown in Figure 2, along with the spectrum for the entire 18 years of data. The peak in the power spectrum for Cycle 21 (1977–1983) at a period of about 153 ± 4 days is quite pronounced, and may be compared with the power spectrum found by Rieger *et al.* for the last $3\frac{1}{2}$ years of the interval, although their normalization is different. It does not appear from these spectra that the same periodicity was present at a significant level during the previous solar cycle, but the longer data base allows us to locate the peak power for the full data set at a period of 151.2 ± 1.8 days. (The side lobe separation corresponds to the 11-year solar cycle.)

We have not estimated the significance of the power spectra because the periodicity does not appear to be sinusoidal. Instead, we have analyzed the time distribution of flares with respect to any assumed periodicities. The histogram of Figure 3 shows the distribution of flares with respect to phase of an assumed period of 151.8 days. (The 151.8 day period was chosen because it maximizes the variance in the phase distribution.) We see that the periodicity takes the form of an impulsive increase lasting perhaps one-half of a solar rotation. The flare count excess in the phase range 0.125–0.200 (7.5% of the assumed cycle) accounts for 45% of the total variance during Cycle 20, 55% of the variance during Cycle 21, and 60% of the variance of the full data set. The phase coherence for the separate cycles is noteworthy.

It is possible to apply a χ^2 test for significance to the hypothesis that flares are distributed

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randomly with respect to phase of the 151.8-day period, but we must be careful to allow for the multiplicity of flares on a short time scale: flares tend to occur in bunches with respect to the 7.5-day resolution of our bins, and this causes the mean number of flares *and* their standard deviation, and hence their χ^2 statistic, to be scaled up by a factor equal to this mean multiplicity. That this effect exists is evident from the fact that the variances are much larger than their expected Poisson values for *all* assumed periods. We have calculated a "mean multiplicity" that reduces the average value of χ^2 per degree of freedom (or the variance divided by the mean) to unity when taken over a large number of assumed periods. We have included all periods from 130 days to 170 days in steps of 0.1 day, and find mean multiplicities of 16.1, 22.5, and 20.04 for Cycles 20 and 21 and the full set, respectively. When these multiplicities are allowed for, we find that for periods of 151.8 ± 0.1 day, the χ^2 values are significant at the level of 10^{-4} for the full data set (with 39 degrees of freedom). This is presumably an underestimate of the significance, since inclusion of data from any real periods results in an overestimate of the mean multiplicities and a corresponding underestimate of the corrected χ^2. For Cycle 20, the χ^2 test is significant at about the 2.5% level for periods of 153.4 ± 0.1 days. For Cycle 21, the significance exceeds the level of 2×10^{-3} for periods near 151.8 days.

An alternative test of significance that is not sensitive to the assumptions made above is the Kolmogorov-Smirnov test. We have applied this test to the same hypothesis, that flares occur at random phases of an assumed periodicity, with times now resolved in bins of 0.002 of the period. We find that for the full data set, assumed periodicities in the range of 151.5 ± 0.3 result in non-randomness at a significance level of 10^{-3}. A comparable significance level obtains separately for Cycle 20, and the significance level for Cycle 21 is better than 10^{-4}. For a large number of periods in the range of 120–180 days, the average Kolmogorov statistic is close to its expected value ($n^{-1/2} = 1/\sqrt{500}$) for a uniform distribution resolved into 500 steps.

Discussion

Our study confirms the recent discovery (Rieger *et al.* 1984) that the occurrence rate of solar flares exhibited a periodicity of about 152 days for the interval between 1980 February and 1983 September. By including microwave data extending back to 1966 April 1, we have found evidence that this periodicity is persistent. The statistical significance of the periodicity in Cycle 20 alone is marginal, but the agreement of period and particularly of phase with those of Cycle 21 gives us more confidence in its reality. From the length of the data set, we can place a formal

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value for the periodicity at 151.8 ± 1.8 days, or at a frequency of 76.2 ± 0.9 nHz.

It is clear from the phase distribution (Fig. 3) that this periodicity takes the form of an impulsive increase in the rate of flares of about a factor of 2 with a duration of 10–15 days, or the typical time for disk passage of an individual feature. Whether the increase is due to such a feature (a particularly strong active region, for example) or to a global excitation with a lifetime of about half a solar rotation cannot be determined from the present data.

Examining the interval around the solar minimum (1975–79), we found no evidence of the 152-day periodicity. It can be seen from Figure 1 that the agreement of large bursts of activity with the expected phase of the 152-day periodicity was predominantly a feature of the years of solar maximum (1969–72 and 1980–82). If the underlying cause of the periodicity was turned off during the solar minimum and turned on later, we would not expect a phase coherence. Therefore, we interpret the lack of periodicity around solar minimum as being due to the scarecity of active regions, and the periodicity in flare events itself as arising from the modulation of an essentially stochastic phenomenon (birth of active regions) by some underlying process of stable long-term periodicity.

Our analysis was also carried out for flares defined by higher thresholds in flux (30 and 100 sfu). The periodicity was not more marked in these cases than for the 10 sfu flares. If we compare monthly flare counts, however, we find that during the solar maximum (1981–82) the number of microwave flares varied from month to month by a factor of 5, but the number of H-alpha flares varied by less than a factor of 2 (Solar Geophysical Data 1983). From this we infer that very small flares detectable by H-alpha observations but with microwave emission below 10 sfu are not strongly affected by the 152-day periodicity. Above this threshold, the periodic modulation operates independently of size on the occurrence rate of moderate and big flares. It should be noted that there is no significant difference in the ratio of recent flares (1980–83) to all flares for the different thresholds 10 sfu and 30 sfu (46.1% *vs.* 44.8%, respectively), despite the greater number of stations and reports in recent years. This suggests that sensitivity to flares at the 10 sfu level has probably not changed.

A possible cause of the 152-day periodicity can be sought in the beating of two incommensurable periods. Since the active regions rotate at about the Carrington rate, the periodicity could be produced by the interaction of active regions or active Carrington longitudes with exciting features rotating at periods of either 23 or 33 days (synodic). The former could represent an

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excitation source in the interior of the sun, while the latter might point to an interaction between high-latitude and low-latitude surface features. In this connection an apparent repetition of the flare increase at intervals of about 30 days should be noted (see Figure 3); it suggests a phenomenon rotating at a characteristic high-latitude rate.

Another possible explanation for long-term periodicities in solar activity is the beating of internal g-modes of different wave-number, as proposed by Wolff (1983). In an analysis of long records of sunspot activity, Wolff found a prominent periodic feature at a frequency of 74.5 nHz, which he interprets as the beating of $l = 2$ and $l = 3$ modes. Our value of 76.2 ± 0.9 nHz is compatible with this interpretation.

References

Kiplinger, A. L., Dennis, B. R., and Orwig, L. E. 1984, *Bull. AAS*, **16**, 891.

Rieger, E., Share, G. H., Forrest, D. J., Kanbach, G., Reppin, C., and Chupp, E. L., 1984, *Nature*, **312**, 623.

Shevgaonkar, R. K. and Kundu, M. R., 1985, *Ap. J.*, **292**, 733.

Solar-Geophysical Data, **474 (Supplement)**, February 1984, U. S. Department of Commerce (Boulder, Colorado, USA 80303)

Wild, J. P., Smerd, S. F., and Weiss, A. A., 1963, *Ann. Rev. Astron. Astrophys.*, **1**, 291.

Wolff, C. L. 1983, *Ap. J.*, **264**, 667.

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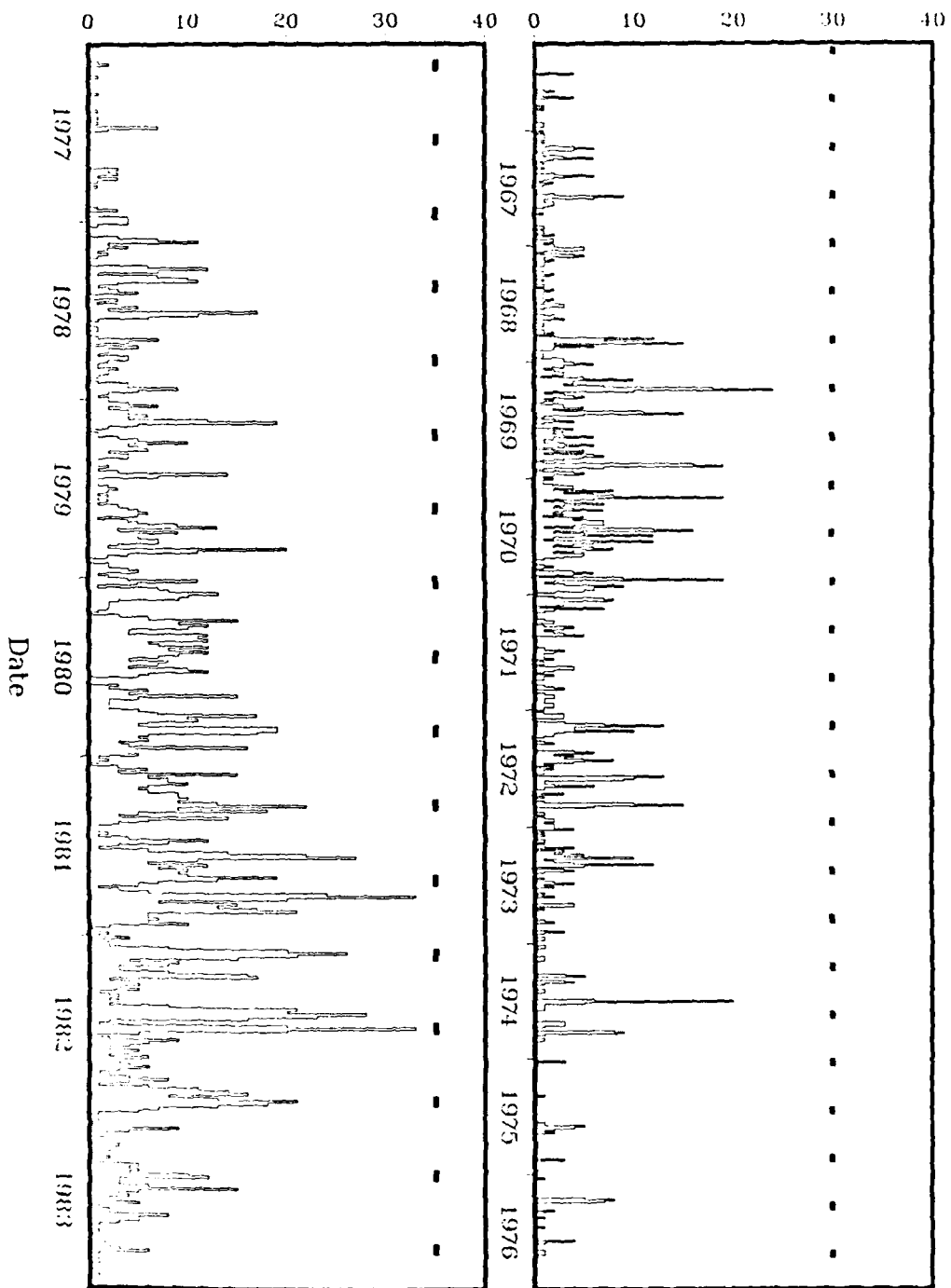
Figure 1. Five-day means of the daily count of flares exceeding the threshold of 10 sfu, as inferred from Solar Radio Noise Data of World Data Center A (see text). Bars are located at times corresponding to the phase interval 0.125 – 0.200 of a period of 151.8 days.
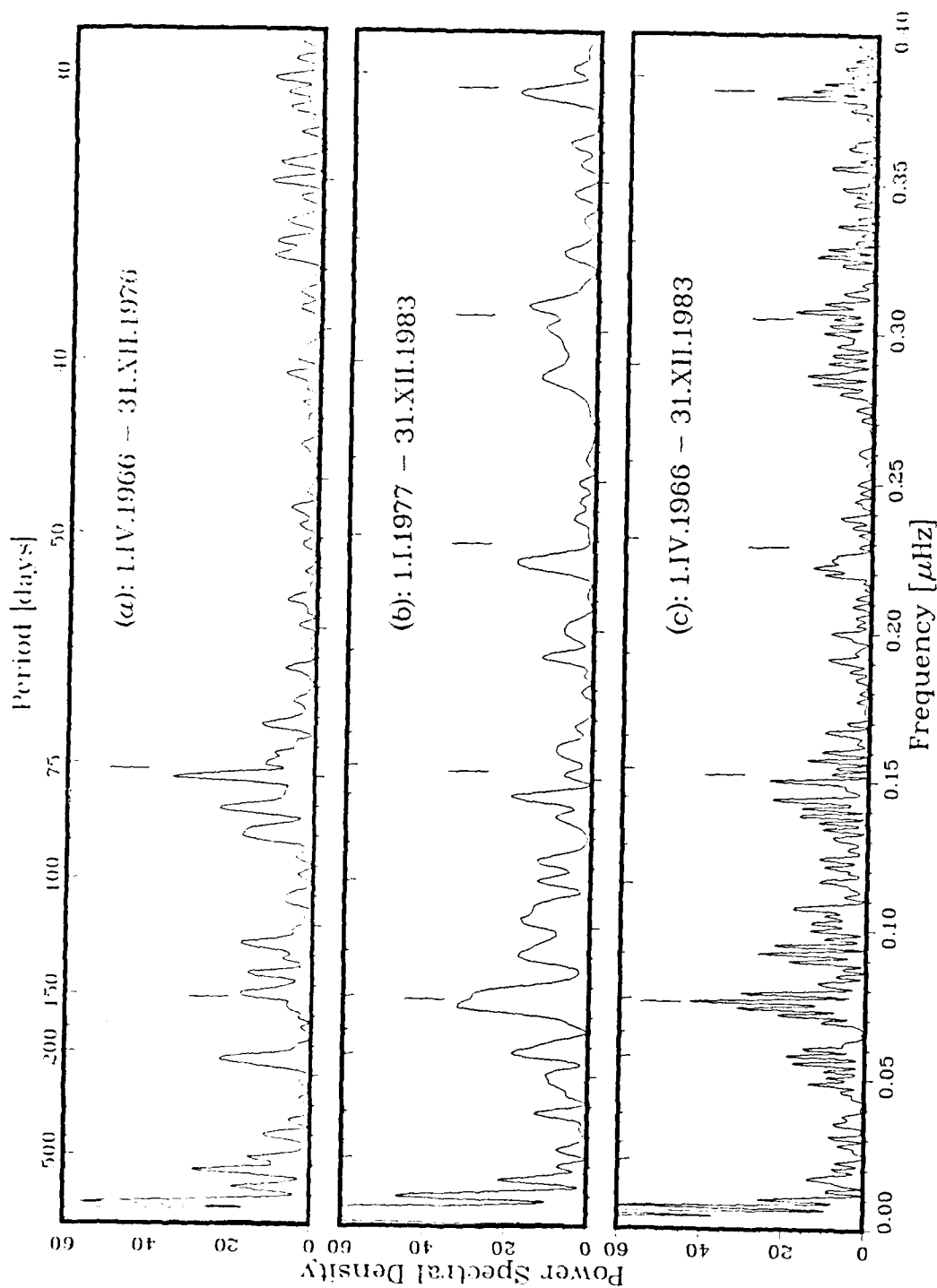
Figure 2. Power spectra of the daily counts of flares for cycles 20 and 21, individually and combined. Tick marks are shown at the frequency corresponding to a period of 151.8 days and at its harmonics where nearby peaks are present.
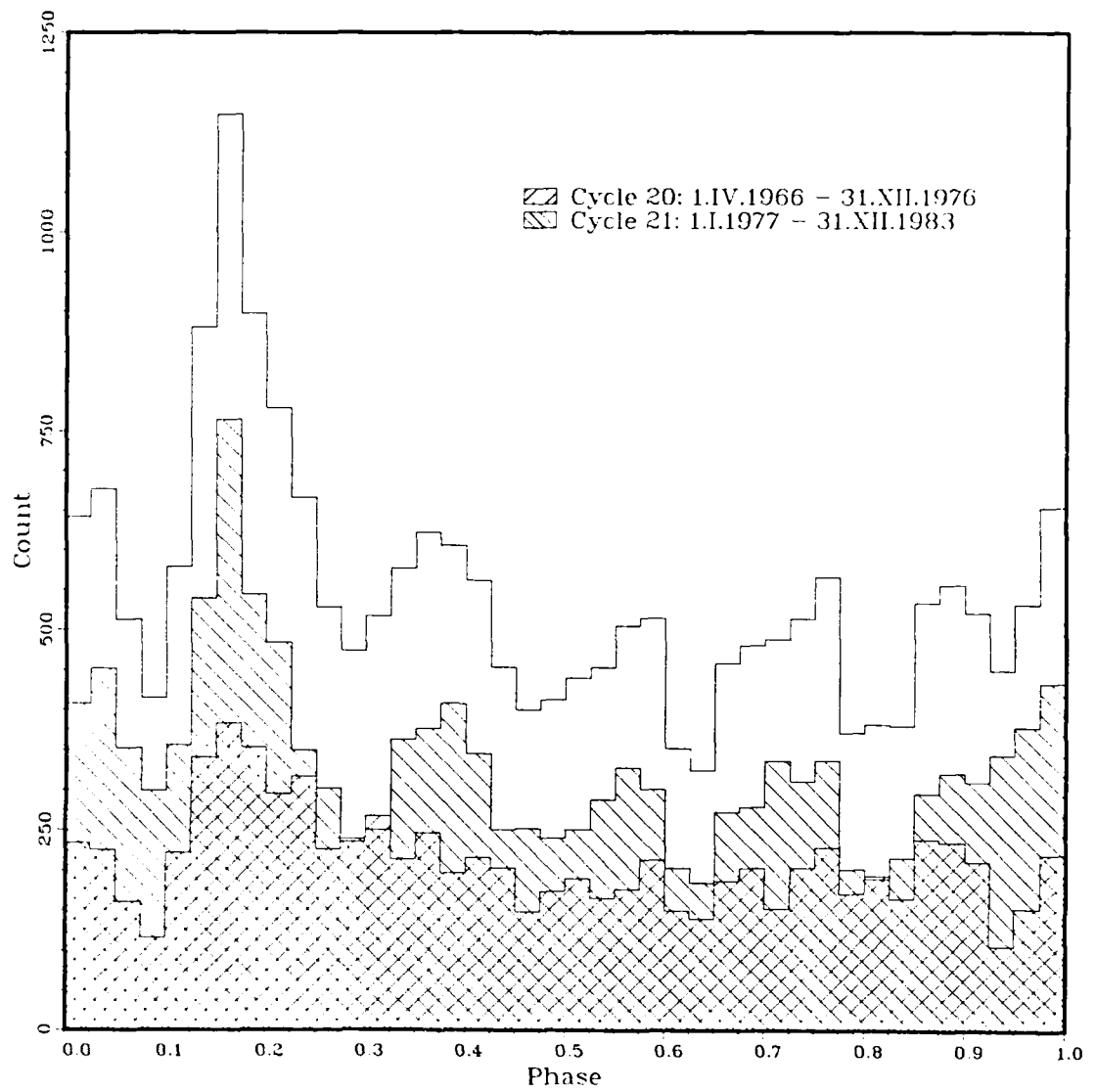
Figure 3. Phase distribution of the starting time of flares with respect to an assumed period of 151.8 days. The zero of phase is taken arbitrarily at 00:00 UT on 1966 April 1.

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